ABSTRACT

This paper develops a multidisciplinary methodology that aggregates remote sensing products and the resources available in geographic information systems – GIS, for transportation planning. The analyzed parameter is accessibility. Public managers can use the accessibility measures in order to promote an appropriate urban planning, mainly the highway network infrastructure and the public transportation system planning. The database was built getting the commercial and industrial (C&I) accessibility index for Osasco Municipality, located in the Metropolitan Region of São Paulo, Brazil. The proposed methodology consists of classifying of the IKONOS II satellite images (by an object-oriented classification) to extract the information necessary to estimate the accessibility index. The goal of this classification is to find the commercials and industrial establishments located in the study area. The spatial data are converted and analysed in a GIS environment and a C&I accessibility index is calculated using the parameters obtained from the satellite images. The main advantages of proposal are it reduction of cost and time spent on field researches or to bring up to recorded data. The commercial and industrial accessibility index by conventional method was calculated, using recorded data available in the Osasco.
Municipality to validate the proposal. These two accessibility indexes are compared, so it is possible to conclude about the applicability of the proposed methodology.

Keywords: Accessibility, Geographic Information System, Remote Sensing, Transportation System.

1. INTRODUCTION

This paper develops a multidisciplinary methodology that aggregates remote sensing products and the resources available in geographic information systems – GIS, for transportation planning. The analyzed parameter is accessibility. Public managers can use the accessibility measures in order to promote an appropriate urban planning, mainly the highway network infrastructure and the public transportation system planning. The paper is organized as follows: this introduction, an overview about accessibility previous works; a description of the objective in Section 3; following, in Section 4, there is a description of the proposed methodology and used materials; a short presentation of the studied area (Osasco Municipality, located in the Metropolitan Region of São Paulo, Brazil) is showed in Section 5; the sections 6 and 7 show a description of the get results and the related conclusions, respectively.

2. AN OVERVIEW

The continuous and disordered urban growth is a world phenomenon and it consists of a serious problem that the cities face presently. Brazil has been undergoing an accelerated process of urbanization, which lasted about 50 years, from the second half of last century.

The industrialization process has encouraged the growth of cities in southeastern of Brazil and has attracted a great migration, from other parts of the country, made up of people seeking better living conditions. The result was a swelling urban, that is, the uncontrolled urban expansion, because cities were not prepared for this rapid growth. Consequently, a process of out skirting the cities. Without economic resources, the population was forced to withdraw more and more central areas of town, where they were concentrated workplaces, hospitals, schools, recreation areas, etc. This situation has continued varying degrees of growth, no longer only in the Southeast, but in virtually all large and medium Brazilian cities.

The peripheral growth of the Brazilian cities is rarely accompanied by an integrated network of public transport and other services. Due to the lack of urban planning (defined by Deák and Schiffer (1999), as a set of actions of spatial ordering of the urban activities, that can not be performed and nor even guided by the common citizen, but should be borne by the State, both in its conception and also in its implementation), with the time went by, this affected the transportation system, because, with the population increasingly distant from their places of destination, travel times and distances to be traveled has increased. As a result, the
transport supply failed to meet the growing demand for transport. So, this was reflected in the quality of transport services that has dramatically decreased.

This could be explained by the fact that the quality of the transportation system is the interface between supply and demand. The measurement of quality depends on the perception of the user. Each person perceives the quality of the transportation system in an individual and subjective way. Since the demand for transport is strongly heterogeneous, with large variations, for instance: income, socioeconomic status, gender, age, education, and so forth; it is quite difficult to gauge which level of service that must be provided, in order to maximize the usefulness of the transportation system user (i.e. minimize travel time and maximize comfort).

The quality of transport service is an imprecise concept, that covers various aspects of the transport system supply, and it deals with abstract and intangible attributes, which are not easily measured. Due to this, their assessment depends on the use of Quality Indicators, such as: travel time (in terms of speed, frequency, headway, reliability), comfort, convenience, flexibility, vehicle conditions (e.g. cleanliness), safety, travel costs / fare level, access to an information system, and accessibility level.

Minocha et al. (2008), conduct a methodology to estimate the quality of the transport service taking into account both the accessibility potential of destinations and the availability of the transportation system to those destinations.

The concept of accessibility is interpreted as a measure of the effort of overcoming spatial separation, in terms of distance, time, or costs (ALLEN et al, 1993). Available opportunities of an individual or group of individuals to perform their activities by taking part in a transportation system characterize accessibility. Accessibility is an inherent characteristic of a place with respect to overcoming some form of spatially operating source of friction (for example, time and/or distance) (INGRAM, 1970).

Khisty and Lall (1998), argue that the basic concept that lies behind the relationship between land use and transport is accessibility. The more accessible an area is to the various activities in a community, the greater its growth potential. It demonstrates the relationship between accessibility and land development, and the advantages of adopting a land use model, based on a realistic measurement of accessibility. Such a model would relate the accessibility of an area to the rate and intensity of the land development in that area (HANSEN, 1959).

According to Minocha et al. (2008), the accessibility concept offers a decision support tool for transportation planners and land use planners to (a) develop an in-depth understanding of the transportation demand and supply that can be served by the transportation system, mainly by transit, within an expected and desired level of service quality; (b) conduct analysis at a relatively small geographic level to develop targeted policies; and (c) allow for detailed analysis of the environmental justice implications of investments in transportation system.
So, the accessibility level affects the quality of the transportation system, and both affect the occupation of the urban land, i.e. the effective land use. The densification of human activities (i.e. the activities system, that is the distribution of opportunities in time and space, for instance: work, school, health system, leisure, so on), occurs around locations with high level of accessibility, both in terms of road networks (transport infrastructure), and transport services.

What is proposed in this study is the adoption of tools that assist the transportation system planning and help to increase the quality of the transportation system, within an Integrated Land-Use and Transportation Model. The measure under consideration is the accessibility, obtained directly from Remote Sensing satellite images, with high spatial resolution.

3. OBJECTIVES

The purpose of the study is to develop a methodological framework to make analysis of Transport Planning using Geographic Information Systems (GIS) provided by the large amount of computing resources from products of Remote Sensing. The main scope is to study levels of accessibility, that serve as tools of urban planning, because they can work to prevent problems related to the transportation network. The accessibility indices assess how is the destinations such as workplaces, education, health, leisure, and so on, can be accessed by the population (users of the transportation system).

The required database is extracted directly from images of high spatial resolution from the remote sensing satellite IKONOS II (details in Machado and Quintanilha, 2008). The study area is the city of Osasco, located in the Metropolitan Region of São Paulo, Brazil. The study consists in getting a thematic map of land use and land occupation of the Osasco City, to locate spatially the companies. This allows the location of commercial and industrial (C&I) establishments of the municipality (with medium or large size). With this information the accessibility index of the business sector of the Osasco is determined (C&I accessibility index).

This methodology is validated by comparing the level of accessibility provided by the proposed method with another one obtained from recorded data (2003), provided by the Municipality of Osasco, i.e. the accessibility index calculated by the conventional model, as calculated by Ingram (1970), and Allen et al (1993). Comparing these two indices of accessibility it is possible to conclude about the applicability of the proposed methodology.

The application of a multidisciplinary approach that uses the remote sensing technology to built the database, and the analysis in a GIS environment to study and measure the accessibility levels is justified by the fact that the construction of the database through research field is more time consuming and costly. The proposal is to reduce the cost and time spent in the research and updates of the recorded data, through a methodology that is useful to places that do not have recorded data or they are outdated and no longer reflect the
reality of the region to be analysed. The proposed method combines agility and costs reduction, because it eliminates the phase of database construction in loco (fieldwork).

4. MATERIALS AND METHODS

For this study, the high spatial resolution images of the satellite IKONOS II were acquired through an agreement between the Government of the São Paulo State and the University of São Paulo. The original imaging was made in October 2002, and the scope of this collection of images includes the 39 Municipalities of the São Paulo Metropolitan Region, with a total of approximately 8,000 km². Many researchers have studied and proved geometric quality of such images. See, for example: Baltsavias et al. (2001); Fraser et al. (2002); Ganas et al. (2002); Jacobsen (2002_A; 2002_B; 2004; 2006); Poon et al. (2005); Shan and Lee (2005); Topan et al. (2005); Kocaman et al. (2006) e Zoej et al. (2006).

As the urban features for the proposed method are mainly roads and buildings (residences, commercials, and industrials), it was decided to perform an object-based image classification as one proposed in Walter (2004). Although these types of features are easily viewed from high resolution images, such as IKONOS II satellite, the most laborious task was to extract them in an automated mode. In this approach, the image classification based in objects, (traditionally to discriminate classes of land cover), seeks also to infer about the land use. However, the classification model based on contextual information (objects) is highly dependent of an analyst.

Several studies conclude that object-based classification of small automated extracted features or ones represented in the images by a few grouped pixels presents better results in urban areas when compared with the traditional pixel-based classification. The reason for this performance is due to the higher spatial resolution of the new generation of sensors that reduce the problem of mixed pixels. Nevertheless, the internal variance and the noise within the classes of land use are extended. Therefore, in conventional procedures of multispectral classification, which compositions of groups (clusters) are based on spectral homogeneities, it results in an excess of classes, i. e., ill-defined classes (SCHIEWE and TUFTE, 2007). A well succeed experiments using objects classification in urban areas related to transportation network can be found in Nóbrega et al. (2006 and 2008) and Quintanilha and Silva (2005).

The proposal method (Figure 1) is described by the following steps:

1. Digital image-processing (images from the satellite IKONOS II):
   a. The four bans (blue, green, red, and infrared) were stacked (overlapped) in order to obtain a single image.
   b. The junction of the different sheets of images was made to compose the study area, i. e., a mosaic of the images.
c. The segmentation of the image creates the objects that will be classified in the next step.

d. A classified image is produced by the classification procedure based on the segments (objects) generated by the segmentation step.

e. The companies located in the study area are geometrically registered with the classification result.

2. Conversion, input, and analysis of the database in a GIS environment:

a. Mapping and labelling the classes generated by the classification algorithm manually.

b. Incorporation of some information about shape, context, and topology, by the visual interpretation and analysis of the image, as well the preliminary classification. A new classification based on this additional information is performed to minimize the errors of the preliminary classification. These are called errors of commission (the segments that were classified as companies, but actually are not), and errors of omission (the segments that were not classified as companies but in fact are).

c. The vectorial data of the Osasco's Municipality record were analysed in this stage. These data refer to the spatial distribution of companies in Osasco (in 2003).

d. Input the data relating to the highway network of the city (recorded data from the Municipality). The streets, avenues, and roads were represented by their central axis, and each start and final point of each stretch corresponds to a node, which make up the intersections or the end of a stretch (the distances were calculated on the highway network).

3. Determination of the accessibility index

a. The accessibility index of the proposed method (database extracted directly from the satellite imagery and the highway network of the city is calculated. It is based on index earlier proposed in the literature: the index of Ingram (1971), and Allen et al. (1993), the spatial separation index. Spatial separation indices take into account only physical aspects, such as measures of distances, time or cost between places of the travel origin and destination. The index adopted didn't consider factors of attractiveness, such as income, population, or number of jobs offered. The proposed index does not include behavioural aspects but it is operationally simple and the results are easy to interpret. As the main objective is to build the database for the determination of the accessibility through remote sensing products and GIS analysis, the adoption of a spatial separation index of accessibility is justified. The adopted index is:
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\[ A_i = \sum_{j=1}^{N} a_{ij} \]

\[ E = \frac{1}{N} \sum_{i=1}^{N} A_i \]

Where:

i. \( E \): index of total accessibility of the study area (C&I total accessibility index)

ii. \( A_i \): index of integral accessibility of the company \( i \) in relation to all other companies \( j \) (C&I integral accessibility index).

iii. \( a_{ij} \): index of relative accessibility of the company \( i \) in relation to the company \( j \) (C&I relative accessibility index).

iv. \( N \): number of the companies.

b. The same accessibility index described above was calculated to the same study area and highway network with the recorded database from the Osasco Municipality.

c. The general accessibility index (\( E \)) was also calculated, using all the intersections of the highway network of the city. So, \( A_i \) became the general integral accessibility index of the point \( i \) in relation to all points \( j \); \( a_{ij} \) became the general relative accessibility of the point \( i \) in relation to the point \( j \); and \( N \) the number of intersection of the highway network.

d. These indices were compared and the consistence of the results verified.
5. DESCRIPTION OF THE STUDY AREA

The study area is the city of Osasco, located in São Paulo State, in the western portion of the São Paulo Metropolitan Region, Brazil (figure 2). Osasco has a total area of 66.9 km², according to the last update of the official census (2007) its population is 701,000 habitants.
The transportation system of Osasco consists of four express highways that cross its territorial boundaries, a wide urban highway network, and a urban passenger railway network. The city also has a system of mass transit by bus, which carries travel within the city, and also between Osasco and other municipalities of the metropolitan region.

Its proximity with the most populous Brazilian city (São Paulo), coupled with its transportation network(mainly the four express highways) facilitates the flow and distribution of goods, services, information and people.

6. RESULTS

The study is based on the extraction of the information that is necessary to calculate the accessibility index directly from high spatial resolution images of the satellite IKONOS II. The software ERDAS Imagine® is used for image overlapping to compose the mosaic and construct the subset of the study area.

The software ERDAS Imagine has been widely used by the remote sensing community to perform digital image processing only in traditional pixel-based classification. As the scope of this research is the object-based classification, the results obtained by this software are exported to another one capable of performing the object-based approach.

To perform the object-based classification, the image segmentation is needed (generation of meaningful objects in the image). Each segment (object), contains a set of contiguous pixels with similar characteristics (e.g. texture, color, etc), and therefore, belonging to the same class. Neubert and Meinel (2003), Meinel and Neubert (2004), and Knapp (2007), conducted comparatives studies among various segmentation programs for high resolution remote sensing applications. According to the authors, the segmentation process available in the
software SPRING (CAMARA et al., 1996), developed by INPE – Instituto Nacional de Pesquisas Espaciais, Brazil, is one of which gives the best results. The combination of these two factors, good performance and the easy availability, was decisive for its utilization in this study.

The segmentation process of the software SPRING is based on similarity. It uses the topological relations of the elements of the image, and applies the procedure of Region Growth, a technique of clustering data in which the regions spatially adjacent may be grouped. Initially, this segmentation process labels each pixel as a separate region. Then, it calculates a similarity criterion for each pair of spatially adjacent region. Then, a similarity criterion for each pair that spatially adjacent region is calculated, based on a statistical hypothesis test (it tests the equality of the spectral attributes between regions). Next, a threshold of aggregation is defined and the regions joined according to this parameter.

In an object-based approach the goal is the use of geometric features, texture, context, and topological relations in order to achieve better performance in identifying the intended targets (in this case the companies), so that, we choose the procedure of region growth in the segmentation process. The polygons generated by the segmentation by region growth were converted to vector format and used as training samples for digital image classification and/or visual image classification, through the assignment of classes to the polygons.

The parameters adopted to perform the segmentation by region growth in the software SPRING were: similarity equal to 30 and area (pixels) to 50. The measure of similarity is based on the Euclidian distance between the mean values of gray level of each region. Thus, two regions are considered distinct if the distance between their means are higher than the similarity threshold chosen. The parameter area refers to the minimum size of area, in number of pixels, that represents a segmented region. Regions with an area lower than the minimum are absorbed by the more similar adjacent regions to them.

The next stage of work is the classification procedure. A preliminary classification using the algorithm Isoseg, performed in software SPRING, classifies regions of a segmented image. It is a non-supervised clustering algorithm. Figure 3 shows the preliminary classification in a part of the study area.

![Detail of the Isoseg classification of the study area](image)

Figure 3 – Detail of the Isoseg classification of the study area
The preliminary classification (by Isoseg) generated 55 classes. They are mapped to transform the classified image into a thematic map in raster format. This thematic map was converted to vector format, exported to a GIS environment and the image reclassification based on objects performed. To accomplish the reclassification of classes, some information about shape and context is introduced in the analysis, with the aim to set the classification rules. This phase was carried out in the GIS software ArcGIS®.

As the focus of the study was the geographical localization of the companies, other classes as vegetation, water, shade, roads, bare soil, residences, etc. are left. For instance, the sub-classes within the class vegetation (many different types of vegetation) are grouped in a general vegetation class and not considered. Similar criterion was adopted for the each other classe. As a result, two groups of information (classes) are obtained: companies (object of interest), and all the rest (all other classes). The result of the object-based classification is shown in Figure 4.

![Figure 4 – Detail of the object-based classification of the study area](image)

After the object-based classification, it was obtained the spatial location of the medium and large size companies in Osasco is obtained by the classification of the polygons as companies. To calculate the accessibility index the centroid of each polygon is calculated by in the software ArcGIS. The result is shown in Figure 5.
Each point (centroid), was allocated on the highway network (logistic network), at the closest intersection (node) to it (see Figure 6), calculated the accessibility index (a spatial separation accessibility index, as described previously) by a specific GIS software to transportation analysis – TransCAD®, which combines the ability of a GIS with transportation modeling procedures, in a single platform,

A matrix with the distances between the company i to all companies j through the highway network is determined. With the companies (points) allocated in the network nodes (intersections), the calculation of the total accessibility is performed as described in las Section of this paper:

- Overall accessibility index to the business sector in Osasco: $E_{\text{companies}}$
- Overall general accessibility index of Osasco: $E_{\text{general}}$
To validate the proposed methodology, the overall accessibility index to the Osasco’s business sector was calculated through the recorded data for 2003 ($E_{recorded}$). The results are presented as follows:

<table>
<thead>
<tr>
<th>Overall Accessibility Index (E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{companies} = 6.54$</td>
</tr>
<tr>
<td>$E_{general} = 5.47$</td>
</tr>
<tr>
<td>$E_{recorded} = 4.21$</td>
</tr>
</tbody>
</table>

7. CONCLUSIONS

The results obtained in this study validate the methodological proposal presented. It is possible to build a database to determine levels of accessibility of a study area directly from remote sensing images.

The indices that were calculated, $E_{companies}$, $E_{general}$, and $E_{recorded}$, are similar and with the same order of magnitude, indicating that the method can be applied and also improved. Moreover, the method may be used in the more accurate remote sensing products for extract the database for urban and transportation planning and analysis. This approach is particularly useful to places where there isn’t recorded data (obtained from field work), or they are outdated. This encourages that more researches and studies are conducted, in order to improve the method and make it more accurate.

The scientific advances in remote sensing technology occur very quickly. This is an area of knowledge that is in full development. The trend is that in short term its application area is expanded and its results show a marked improvement.

REFERENCES


Jacobsen, K. Comparison of High resolution mapping from space. In: XXIIº INCA – Indian National Cartographic Association Congress, Proceedings, Ahmedabad, India, 2002_B.


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International Conference on Object-Based Image Analysis, 2006, Salzburg - Austria. OBIA'06 - 1st International Conference on Object-Based Image Analysis, 2006.


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